Decentralized Motion Control of Two Tracked Mobile Robots Transporting a Single Object in Coordination Based on Function Allocation Concept

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Extended Abstract

1. Introduction

When we would like to handle a large or heavy object, we do it in cooperation with others. It is a natural extension of such a behavior of humans for multiple robots to cooperate each other when they handle a large or heavy object. Much research has been done for the motion control scheme of multiple mobile robots to transport a single object in coordination [1]-[4] etc.

Centralized control scheme is not a realistic way to realize the coordination considering the communication cost among robots. Several research works have been done for the decentralized motion control of such mobile robots handling a single object in coordination [2][3][4] etc.

We have proposed a leader-follower type of decentralized motion control algorithm for holonomic robots [3] and extended the algorithm to nonholonomic tracked-vehicles [4]. In these algorithms, a motion command of the object is given only to the leader and the rest of the robots referred to as followers estimate the commanded motion without communication among robots.

In this paper, we propose a collision avoidance system for two tracked-mobile-robots transporting a single object in coordination based on the function-allocation concept. We implement the proposed algorithm in the two experimental tracked mobile robots and illustrate the validity of the proposed system.
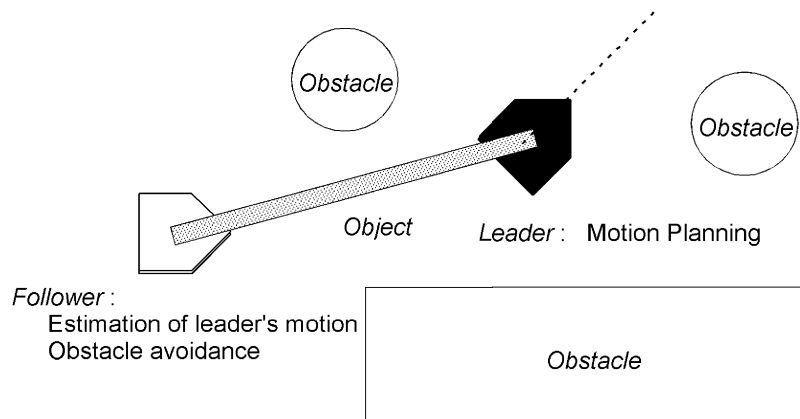

Fig.1 Function-allocation Concept

2. Outline of Control Scheme

Consider a motion control problem of two tracked mobile robots for handling a single object in coordination. We assume that the object is rigid and supported by both robots through rotational joints attached to the robots to avoid the nonholonomic problem. In the decentralized motion control system, which we propose in [4], the motion command of the object is given only to the leader and leader moves according to the command. The follower is controlled so as to align its orientation with the object motion direction by emulating the motion of a caster, which is referred to as the dual-caster action [4].

In this system, the orientation of the object is determined by the position of the rotational joint of the leader and the position of the rotational joint of the follower. The position of the follower is determined according to the dynamics of the dual caster action. It is not an easy job to predict the motion of the follower, since the dual caster action depends of the force applied to the follower.

In this paper, we modify the control algorithm proposed in [4] and implement a collision avoidance algorithm based on function allocation concept. We will show that the collision avoidance is possible by controlling the translational motion direction of the follower independently of the motion of the leader. In this system, the collision avoidance is realized by the follower's behavior, while the object motion is controlled by the leader based on the motion command given to the leader. The transportation of the object is thus realized by different functions allocated to the leader and the follower as shown in fig. 1.

3. Collision Avoidance

As shown in Fig.2, when the distance between two grasping points of the object, or the rotational joints attached to the leader and the follower, is L, the relative position of the follower is restricted onto the circle whose radius is L and whose center is located at the rotational joint of the leader. Thus, whenever the follower generates the collision avoidance motion, we need to restrict the follower's motion onto this circle. First, we consider the avoidance motion based on the motion constraints of the object. As we assume that the leader does not take the collision avoidance motion for the object, the possible motion to avoid obstacles is the rotational motion of the object around the rotational joint of the leader.

Let p_i be the point on the object closest to the i-th obstacle as shown in fig.3. Let r_i be a vector perpendicular to the heading direction of the object as follows;

$$r_i = h_i y_o \qquad (1)$$

where h_i is the minimum distance between i-th obstacle and the object and y_o is a unit vector of the object coordinate frame.

The avoidance velocity vector V_{avd} is generated as follows;.

$$V_{avd} = \sum_i \left\{ V(r_i) \cdot \frac{L}{l_i} \right\} \qquad (2)$$

$$V(r_i) = \frac{k}{|r_i|^2} r_i \qquad (3)$$

where l_i is the distance from the grasping point of the leader to the point p_i. $V(r_i)$ is the magnitude of the avoidance velocity and a function of r_i. k is a constant.

From eqs. (2) and (3), we generate V_{avd} perpendicular to the heading direction of the object. But we cannot always generate the velocity vector V_{avd} because of the motion constraints of the follower. Let us consider the motion constraints of the follower along the motion direction of the object, next. The follower estimates the motion of the leader along the motion direction of the object and has to generate the velocity along this direction.

As shown in Fig.4, let P and Q be the positions of the rotational joints of the leader and the follower respectively. Let V_l be the velocity of the leader at the point P, and V_f be the velocity of the follower at the point Q. Let θ_{Vf} be the angle between the vector from P to Q and V_f. From Fig.4, the component of the velocity V_f along the heading direction of the object is $V_f \cos\theta_{Vf}$. The orientation of the follower is calculated as follows;

$$\theta_{Vf\_avd} = \tan^{-1} \frac{\left| V_{avd} \right|}{\left| V_f \cos\theta_{Vf} \right|} \tag{4}$$

As long as θ_{Vf_avd} satisfies the following inequality,

$$-\cos^{-1}\frac{1}{3} < \theta_{Vf\_avd} < \cos^{-1}\frac{1}{3} \tag{5}$$

the follower can estimate the motion of the leader at its translational motion direction. The follower's heading direction is controlled to keep θ_{Vf_avd} and the collision avoidance motion is realized.
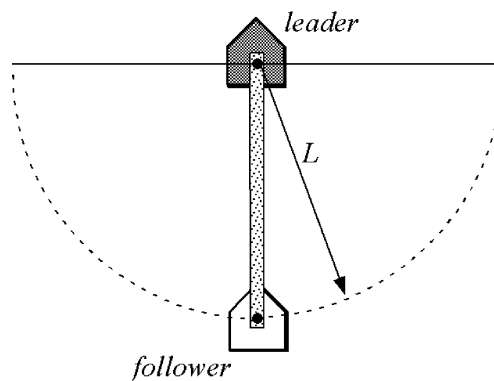

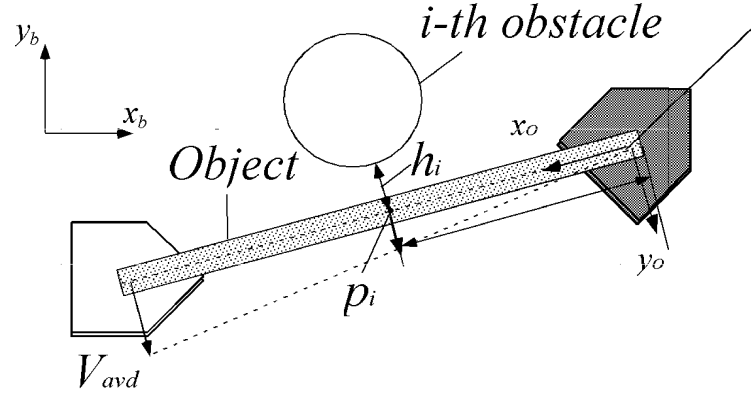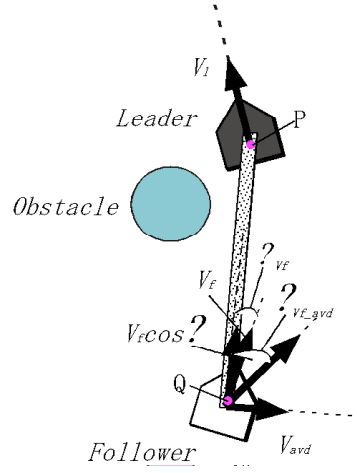Fig.2 Follower's Motion Constraints

Fig.3: Velocity V_{avd}

Fig.4 Motion direction of Follower

4. Experiments

The proposed system was implemented in the experimental system, which consists of two tracked mobile robots as shown in Fig.5. Each robot has a force sensor at the rotational joint, which the object is connected to each robot through, and is controlled by its onboard controller. The desired trajectory was given only to the leader, and the follower was controlled using the proposed algorithm in section 3.

In the experiments, the leader was first commanded to move along a straight line with its orientation constant. Then the leader changed its motion orientation, and moved along a straight line again. We compare the follower's motion by the proposed system in this paper and with the one proposed in [4]. The results are shown in Fig.6. Note that "follower 1" is the follower with the control system proposed in this paper, and "follower 2" is the follower with the system proposed in [4]. As shown in Fig.5, the trajectory of follower 1 follows the leader and avoids the obstacles successfully, while the trajectory of follower 2 collides with the obstacle.

5. Conclusion

In this paper, we propose a collision avoidance system for two tracked-mobile-robots

transporting a single object in coordination based on the function-allocation concept. We implemented the proposed algorithm in the two experimental tracked mobile robots and illustrated the validity of the proposed system.
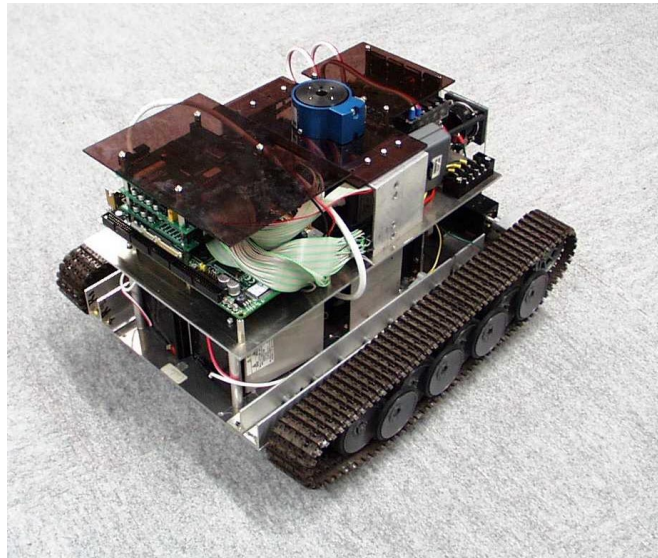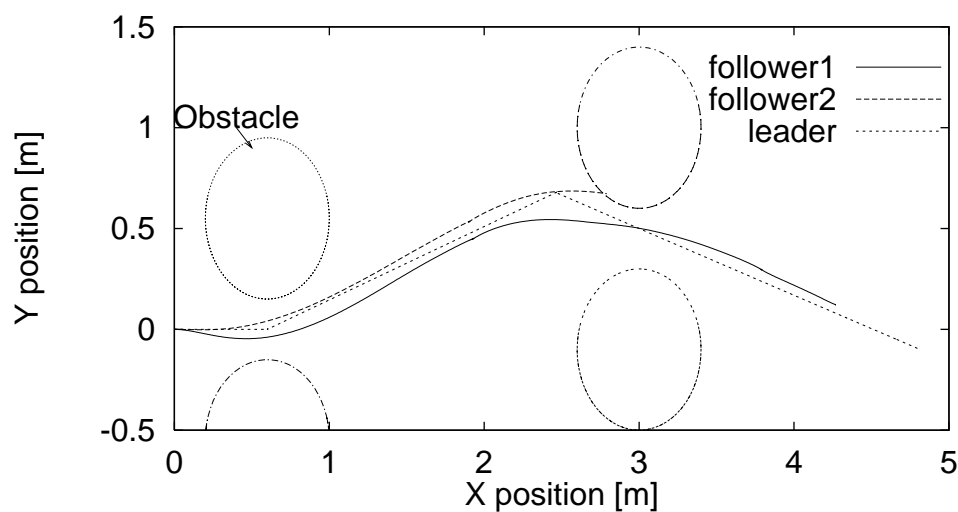

Fig.5 Experimental System

Fig.6 Trajectory of leader and follower

References

[1] M. Hashimoto, F. Oba, T. Eguchi, "Dynamic Object-Transportation Control Method by Multiple Mobile Robots", Journal of the Robots Society of Japan, Vol.13, pp.886-893, 1995.(In Japanese).

[2] J. Ota, Y. Buei, T. Arai, H. Osumi, K. Suyama, "Transferring Control by Cooperation of Two Mobile Robots", Journal of the Robots Society of Japan, Vol.14, pp.263-270, 1996.(In Japanese).

[3] K. Kosuge, T. Oosumi, "Decentralized Control of Multiple Robots Handling an Object",

Proc. of 1996 IEEE Int. Conf. on Intelligent Robots and Systems, pp.318-323, 1996

[4] K. Kosuge, T. Oosumi, M. Sato, K. Chiba, K. Takeo, "Transportation of a Single Object by Two Decentralized-Controlled Nonholonomic Mobile Robots", Proc. of the 1998 IEEE Int. Conf. on Intelligent Robots and Automation, pp.2989-2994, 1998